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CDF and D0

Radiation Monitoring for Vertex Detectors at the Tevatron

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For the CDF and D0 Collaborations

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Radiation Monitoring for Vertex Detectors at the Tevatron

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Abstract

I present an overview of radiation monitoring for vertex detectors and the abort system for the Fermilab Tevatron. Details on the detectors, inputs, and measurements for the Run 1 time period are provided. Plans for the monitoring during Run 2 are discussed. The measurements imply an approximately even mix of radiation from beam-beam collisions and beam losses.

1 Introduction

The Tevatron has run as a 900 GeV proton-antiproton collider in various periods since 1987. With a circumference of 2π km, the revolution period is 21 μ sec. During Run 1A, which covered the time period 1992-1993, an average store had $1e12$ particles and a total of $\approx 30 \text{ pb}^{-1}$ delivered luminosity. The CDF Collaboration had a vertex detector (CDF SVX) [1] with single sided DC coupled sensors connected to radiation soft readout electronics (the SVXD chip). During Run 1B, which covered the time period 1994-1996, the average particle intensity doubled to $2e12$ and there was a total of $\approx 120 \text{ pb}^{-1}$ delivered luminosity. The CDF Collaboration had a vertex detector (CDF SVX') [2] with single sided AC coupled sensors connected to radiation hard electronics (the SVXH chip). In Run 2, scheduled to start in spring 2000, the beam energy is expected to increase to 1 Tev per beam and the beam intensity to go up to $1e13$ total particles. The stated goal is delivery of 2 fb^{-1} . Both the CDF (CDF SVXII) [3] and D0 (D0 SVX) [4] collaborations plan on having vertex detectors using double sided AC coupled sensors with radiation hard electronics (the SVX3D chip for CDF, the SVX2 chip for D0).

2 Beam Loss and Abort at the Tevatron

There are several time scales for beam loss at the Tevatron, ranging from 100's of hours to 10's of μsec . The single beam lifetime (without particle loss from collisions) is on the scale of 100's of hours and is not a significant effect in radiation to vertex detectors. The luminosity lifetime, dominated by the particle loss through collisions and emittance growth, is on the time scale of 10's of hours. Though a slow time scale, the particle flux from collisions is a significant source of radiation for vertex detectors (of course, it is good in that the detectors see particle collisions and detect vertices!). Device failure, such as problems with power supplies, diagnostic, cryogenic, or vacuum equipment, is a major source of beam loss and has time scales ranging from milliseconds to seconds. Standard manipulations of the beam (e.g., the transition from the injection lattice to the low β collision lattice) are also a major source of beam loss with time scales in the seconds to 10's of seconds range. Finally, the fastest loss mechanism is a pre-fire (unintentional firing) of the abort kickers, which has a time scale of 1 revolution (21 μsec). Most of the loss mechanisms have growth rates long compared to the revolution period.

To protect the superconducting magnets in the Tevatron, the abort system was designed to do a single turn abort with a fast kicker rise time during a designed abort gap [5]. The abort system has concentrator modules in 24 locations around the ring, with standard inputs from vacuum equipment, power supplies, quench protection monitors, and beam loss monitors (described below). Each concentrator module serves as a repeater for a 5 MHz permit signal, taking away any of the inputs drops the repeater and the permit signal. When the gap in the permit signal has propagated to the kicker location, there is at most 1 revolution period to time in the abort gap and fire the kicker.

The Tev beam loss monitor is a 110 cc argon ionization chamber, operating close to standard temperature and pressure. It is connected to a log-integrating preamplifier and calibrated to a direct scaling of rads/second into the monitor. The abort threshold is set at 10 rads/sec during low field operation, dropping to 1.5 rads/sec at high field (as the beam energy has gone up by a factor of roughly 7). The standard loss monitor has an integration time constant of 60 msec.

Simulations of beam loss around the Tevatron interaction regions predict approximately 5×10^{-8} rads deposited in the vertex detectors per proton lost. As the original CDF SVX, with rad soft electronics, had an expected lifetime of around 30 krad (when the noise would double) and there was 1×10^{12} particles circulating in the Tevatron, a total beam loss would lead to 50 krad. Therefore, a monitoring and abort system was designed specifically to protect the CDF SVX.

3 CDF Run 1 System

The CDF Run 1 radiation monitor and abort system used two different measurement methods. First, a set of thermoluminescent dosimeters (TLDs), sensitive to ionizing charged particles, were used to measure a total radiation dose. Located in an array at ± 2.5 m from the nominal interaction point, they were at 3 different radii and 6 azimuthal positions. The arrays were changed at quasi-monthly intervals. The second method made use of the beam loss monitors discussed in the previous section. Located just downstream of the TLDs on the inside and outside of the beam pipe in the plane of the Tevatron, the BLMs gave both an integral measurement and an instantaneous rate.

The BLMs were connected to a log-integrating preamplifier with an integration time constant of 960 msec. The output of the preamplifier was fed to a special purpose CAMAC module. On this module there was an 8 bit ADC, sampled every 10 revolution periods ($210 \mu\text{sec}$), digital comparators for both alarm and abort thresholds looking at the ADC output, a 2k deep cyclical buffer, and an microprocessor to integrate the waveform. The abort thresholds were set at 10 rads/sec during injection and machine study periods and 2 rads/sec when stable beams reached collision.

Of the 265 proton-antiproton stores in Run 1A, 6 were aborted by the CDF BLMs only. 2 of these were hardware failures (power to the CAMAC crate failed, taking away the beam permit), 1 during tuning, 1 followed a corrector magnet power supply trip, 1 from local losses, and 1 by hand. In Run 1B, of the 520 stores only 2 were aborted by CDF only (vacuum problems). Aborts were more frequent during studies periods, when the Tevatron was not at stable operating points. There were many other stores where the abort threshold was reached at CDF but they were consistent with losses elsewhere in the ring. As the interaction region low β systems are a high loss point, the BLMs in the interaction region would often be the first to reach the abort thresholds though other regions were approaching the threshold. There were multiple instances where the ‘early’ abort from the CDF BLMs saved the Tevatron from quenching and made re-establishment of beam collisions quicker and easier.

4 CDF Run 1 Experience

In figure 1, an hour of recorded radiation and luminosity information is displayed. The first 25 minutes cover the time period of beam injection (little or no recorded radiation), the low β transition (from injection lattice to collision lattice after the energy ramp) as demonstrated by the change in the low β

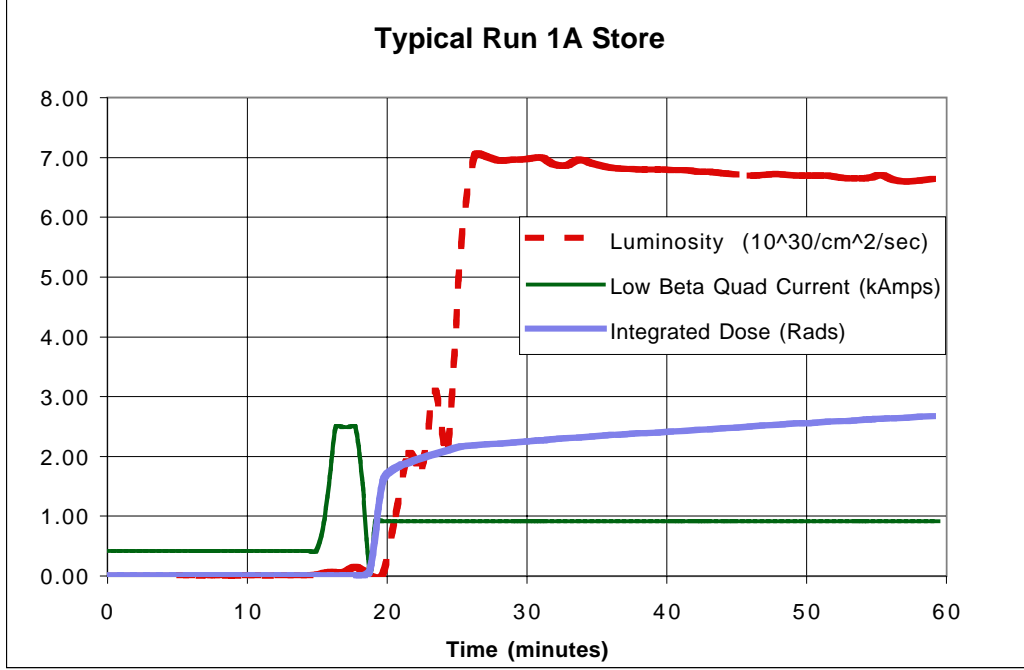


Fig. 1. A time history of a typical Run 1A store. The integrated dose (in rads), the instantaneous luminosity ($10^{30}/\text{cm}^2/\text{sec}$) and low β quad current (kAmps) are displayed for a 1 hour time period.

quad current, the preparation of beams for collision, and the start of physics operation. During this period, there is a sharp step in the integrated radiation during the low β transition (about 1.5 rads in 30 seconds), followed by a medium rate as the beams are prepared for collision. The final 35 minutes show a steady growth in the integrated radiation associated with the particle flux from beam collisions. In figure 2, the cyclical buffer (covering 400 msec) is shown for one particular abort. Note the slow growth in the radiation (10's of msec time scale) and then a faster growth (100's of μsec) near the end. This level was the highest instantaneous rate seen during collider Run 1, approximately 16 rads/sec. It occurred during the low β transition with the threshold set at 10 rads/sec.

It was expected that there would be some mix of radiation from beam collisions (expected to fall as r^{-2} , where r is the radial distance from the beam) and beam losses (expected to fall as r^{-1}). With measurements from the TLD arrays (3 radial points), the best fit in Run 1A was $r^{-1.5}$. Since the CDF SVXD chip performance changed significantly during the course of Run 1A due to radiation damage, one can also fit the change in noise and electronic gain versus radial position. In figure 3, the noise and gain normalized to the initial (0 radiation) values are plotted versus radius. Overlayed are the expected noise and gain curves, using a radial dependence of $r^{-1.5}$ and extrapolating from the TLD and BLM longitudinal position. The normalized noise follows the $r^{-1.5}$ curve very well, while the normalized gain actually falls faster. A $r^{-1.5}$ behavior

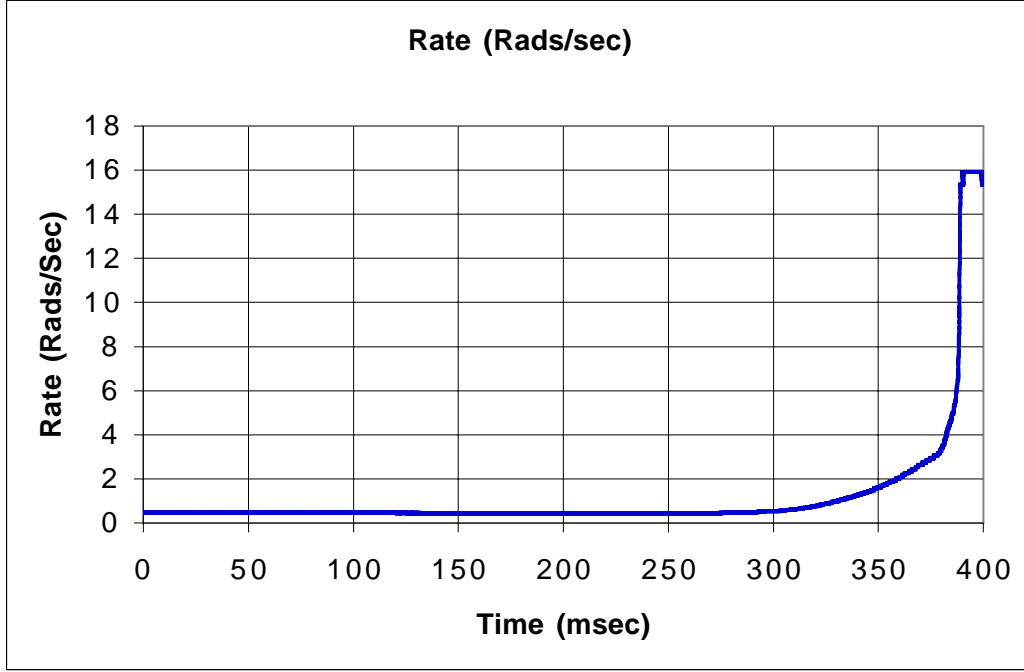


Fig. 2. A sample abort time history. This abort had the highest instantaneous rate (16 rads/sec) seen during collider Run 1 and occurred during the low β transition, at which time the threshold was 10 rads/sec. Note the jump from 8.5 rads/sec to 16 in one sample time (210 μ sec).

is consistent with a 50 - 50 mix of r^{-2} and r^{-1} , meaning that the luminosity and loss dose are roughly equivalent.

In figure 4, the total radiation at the innermost radii (≈ 3 cm) is shown for Run 1A and 1B. Note that once past the startup period, there is a linear dependence of radiation on the luminosity, again meaning the mix of luminosity and loss dose stays roughly equivalent even during stable running. For Run 1A, the slope was 300 rads/pb $^{-1}$, for 1B, 550 rads/pb $^{-1}$. The difference between the two slopes is not understood. Even with the startup problems, it was found to be very difficult (if not impossible) to dump significant fractions of the beam in the interaction region.

5 Run 2 Plans

CDF plans to duplicate the same system used for Run 1: a combination of beam loss monitors and TLDs. Due to changes in the detector, the monitor positions will change. They will move from $\approx \pm 2.5$ m upstream and downstream of the interaction point to $\approx \pm 4$ m. The abort thresholds may be adjusted based on operating experience.

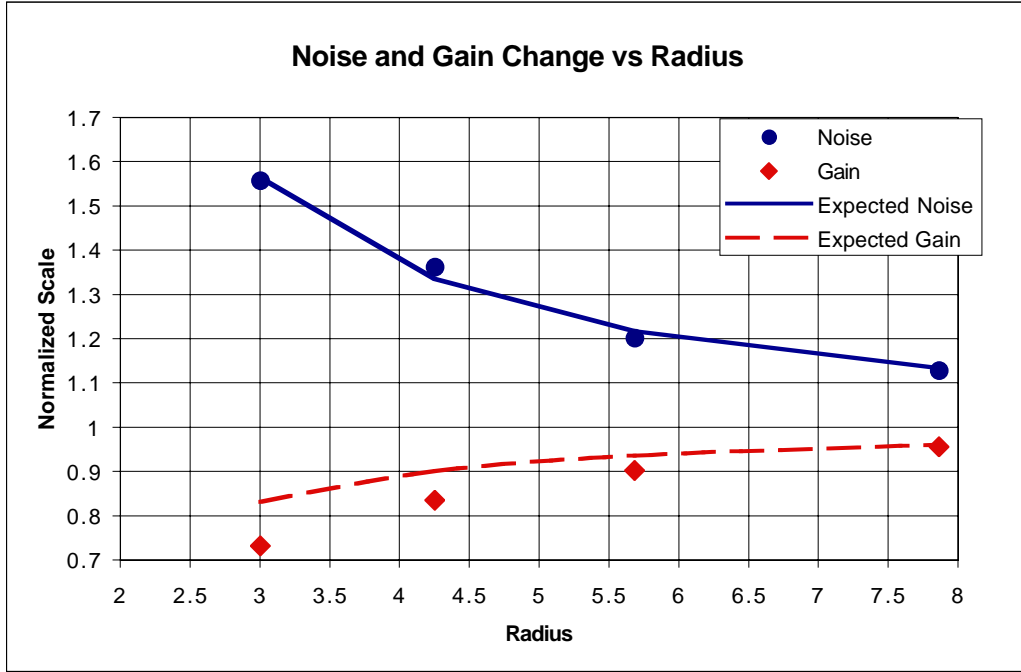


Fig. 3. The normalized noise and gain change due to radiation damage as a function of the radial distance from the beam. The lines are the expected change for a $r^{-1.5}$ behavior.

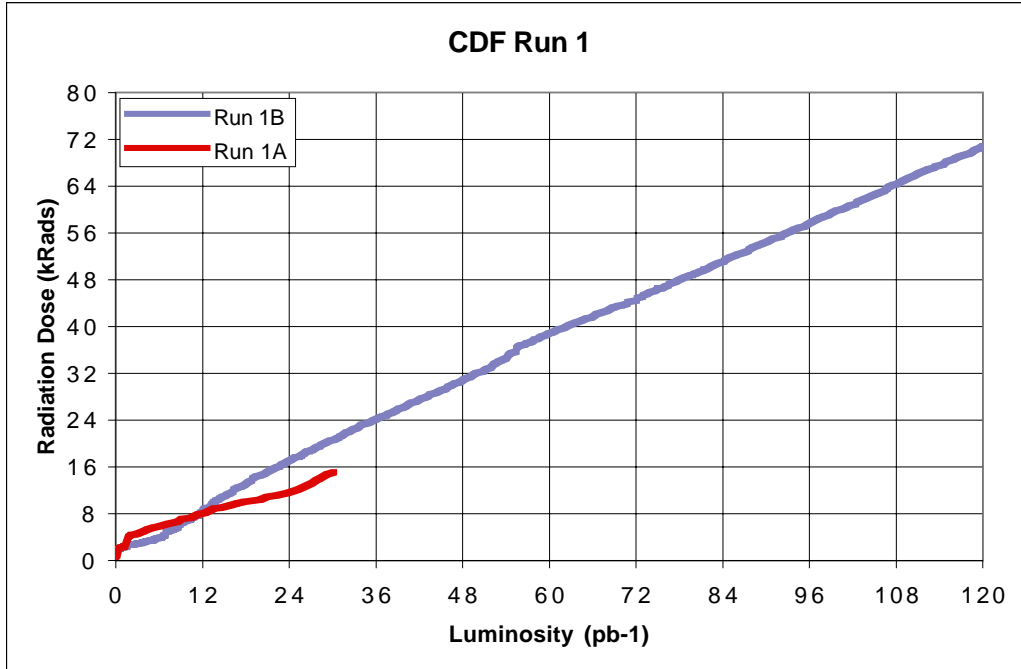


Fig. 4. The total extrapolated dose to the inner most layer (at ≈ 3 cm) for the Run 1A and 1B periods. Once past startup, the dose is linearly dependent on the delivered luminosity, meaning the 50 - 50 mix of luminosity dose and loss dose stays roughly equivalent even during stable running.

D0 plans to use both beam loss monitors and large surface Si diodes as radiation monitors. There will be 8 BLMs, located just outside the calorimeter cryostat, connected to a log integrating preamplifier and interfaced to the Tevatron abort. As the D0 cryostat is very hermetic, it may be difficult to extrapolate from the BLMs (probably more sensitive to losses than luminosity) to the vertex detector. The second set of monitors, large surface Si diodes, will be mounted directly on the the vertex detector.

In the forward region, silicon disks with a wedge geometry will be used [4]. The Si diodes will be mounted on the same bulkheads and will therefore sample the same luminosity and loss dose as the detectors, giving information at the exact location of interest (rather than extrapolating as the CDF monitor system requires). The current in the diodes will be integrated over various time scales and stored in cyclic buffers, which are available for display. 1 minute long averages will be archived for long term measurements. The electronics can be gated to look at single beam crossings, allowing for a direct calibration of single particle currents. This Si diode system will be very similar to one successfully used previously by the OPAL collaboration [6].

6 Conclusions

Radiation monitoring systems useful for both total dose measurements and as inputs to machine aborts have been successfully developed for the vertex detectors at the Tevatron. They have been shown to be efficient and reliable, with most aborts correlating with recognizable machine problems. The radial dependence of radiation dose has been measured to be $r^{-1.5}$, an even mix of that expected from beam collisions (r^{-2}) and losses (r^{-1}). It is difficult to dump all the beam in the detector locations, as most loss mechanisms have long time scales compared to the sensitivity of the loss monitors and the Tevatron abort hardware. Significant accidents only occurred when the Tevatron lattice was perturbed (energy ramp, low β transition, device failure) and not at well understood operating points.

7 Acknowledgments

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